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W. F. GETTELMAN
C. B. LITTLE

THE DESIGN OF A PROPOSED POWER PLANT ON ZUMBRO RIVER AT ZUMBRO FALLS, MINNESOTA

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THE DESIGN OF A PROPOSED POWER PLANT ON ZUMBRO RIVER AT ZUMBRO FALLS, MINNESOTA

A THESIS
SUBMITTED BY

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FOR
THE DEGREE OF BACHELOR OF SCIENCE
CIVIL ENGINEERING COURSE

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1914

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INTRODUCTION

It will be the purpose of this thesis to explain the method of design involved in the development of a water power project, and by the use of a specific example, show the problem confronting the engineer in practice, a problem which may be summed up in a few words, " Here is the river; develop power"

The river in question in this thesis is the Zumbro River in the southeastern portion of the State of Minnesota. It will be the object of this thesis, then, to investigate the Zumbro River from such sources of information obtainable for a suitable site for water power development, determining this site from what is considered good judgement in actual engineering practice, and outline a design for the construction of a power plant on the site selected.

In the location of this site, there will enter into question of judgement, various factors which influence the decision of an engineer, such as, the amount of power available at a selected point, the geology and topography of the site, the security of foundation, the functions of the stream flow, the financial success of the project, and various other minor items, all of which have to be weighed for the particular importance relative to the site selected.

With these factors once defined for any project, the adoption or the failure of the plans may be predicted. An engineering project is as dificult to reject in many instances as it is to accept, and one of the points of the thesis will be to determine the feasibility of the development on the Zumbro at

Zumbro Falls.

In general the outline of the thesis will consist in a study of the stream flow, the computation of the power available, the selection of the site, the construction plans, and a statement of the feasibility of the finances to be involved.

W. F. Gettelman

C. B. Little

CHAPTER I

THE ZUMBRO BASIN AND POWER SITES

CHAPTER I

One of the first problems encountered in a water power project, is the extent and the location of the drainage area of the river on which the project is to be located. It is sometimes evident from the knowledge of similar drainage areas in the same portion of the country to predict directly the success or the failure of a project by knowing the extent and location of the drainage basin.

The Zumbro river drains an area comprising approximately 1390 square miles, bounded by the Cannon River Basin on the north, and the basin of the Root River on the south. The basin is located chiefly in Wabasha, Goodhue, Dodge, and Olmstead counties in southeastern Minnesota.

The North Branch of the Zumbro River rises in the southeastern part of Rice County, flows eastward. The South Branch is formed by a number of small tributaries in the south western part of Olmstead County, and flows north receiving throughout its course other tributaties, the largest being Middle Branch. In the western part of Wabasha county the two streams unite to form the Zumbro River, which takes a general easterly direction until it reaches the flood plains of the Mississippi River, where it empties into one of the sloughs of the region.

During its course of construction of the river bed, the present river has cut valleys from 100 to 200 feet deep below the general level of the surrounding country. The cutting of these valleys through the characteristic strata of the country in this

section has formed a channel for the North and South branches. The bluffs of the valleys formed in this nature offer ideal conditions for water power sites when they are found with sufficient flow of water to warrant development

As the river approaches its mouth, or the slough into which it empties, these valleys of the two branches form one at the junction of the river, and the bluffs on either side become higher and higher from the level of the river until the valley at the mouth of the river is nearly 400 feet deep, bounded by rough cliffs of sandstone; the width of the river is varying, ranging from one to two miles during the course of the river.

There are numerous small streams flowing into the Zumbro at the present time; all of which deposit on the flood plain more material than the Zumbro itself is capable of carying away, and naturally, the valley is gradually filling up.

In addition to these sources of supply, there is another source contributing quite a large share of water to the river. A number of large springs issuing from the bluffs add their overflow to a number of similar sources located at the headwaters of the river.

The region surrounding the river is in general an undulating prairie which has been more or less eroded by the action of the streams formed during spring floods, leaving well defined valleys cut to a depth equal to the thickness of the soil on the sandstone foundation beneath. In many cases the action has even cut into the glacial drift sandstone, thus causing permanent beds for the flow of the water at these periods.

There is one noticeable characteristic of this section of the country,- the abscence of any large forest land. The majority of the land in the Zumbro basin is under cultivation, the land for which has been cleared of the original forest in this teritority before the settlement.

Another characteristic of the valleys of the Zumbro, if it is compared to the streams of Northern Minnesota and Wisconsin, is the total absence of lakes throughout the drainage area. The upland districts are, in general, flat without resorvoir facilities, and hence the only available pondage is by the damming of the river between the bluffs.

The underlying strata in this basin are sandstone and shales of the Silurian and Cambrian ages. On top of this basic material is a covering of blue till, a glacial deposit, consisting of sand, clay, and gravel, ranging in depth from a small skin-like deposit in the central portion of the basin, to a comparatively thick deposit in the extreme west end.

The river has a good fall throughout its course, and there are many places where small plants for the development of water power may be satisfactory. In further discussion of the power sites, a list of the developed power sites will be given with a list of the feasible sites.

In addition to the water power development there are excellent opportunities for drainage in the flat upland marshes. While this project isnnot becoming very prominent, yet up to the present time approximately 34,000 acres have been drained.

POWER SITES

Developed

On the Zumbro River, there are at present several small power developments, all operating under satisfactory conditions. They are as follows:-

Zumbrota,- At this point a flour mill with a timber dam has been constructed which gives an eight foot head. The back-water extends for one mile upstream. The construction of the dam, in brief, embodies a flume 30 ft. long, which supplies water to a turbine of about 10 horsepower. The details of the turbine itself are unknown. The operation of the plant is intermittant and no steam auxiliary power is used.

Forest Mills,- The Forest Mills and Elevator Company has built a timber dam producing a head of eleven feet, which backs the water into a small natural reservoir one mile long and 150 feet in width. In the mill itself which is located some distance downstream, has been installed a 36 inch duplex turbine of 50 horsepower. The water is supplied to the turbine by means of a canal and cast iron pipe system from the dam. The turbine is belt-connected to the machinery, and is operated intermittantly withour steam auxiliary power since the power developed is sufficient for the demand.

Mazeppa,- One of the larger developments is located at the town of Mazeppa, where the Mazeppa Roller Mill has erected a patent timber dam. The inclined upstream face of the dam is supported by a frame work of timber on the downstream side. The abutments are of masonry. This dam enables a 22 foot head to be

obtained, backing the water about 2 miles upstream. At the left end of the dam is located the mill, in which are installed the turbine equipment, consisting of one 22 inch Special Leffel turbine of 60 horsepower capacity, and one 14 inch Samsom Leffel turbine of 24 horsepower capacity. The water is supplied to the turbines through a short iron penstock leading from the dam. The large turbine is belt-connected to the machinery of the mill, while the smaller operates a small electric generator for the town. There is an auxiliary steam power plant of 50 horsepower, although the water supply is sufficient. The operation of the plant is 15 hours per day.

Jarretts,- The Jarrett Roller Mill Co. has erected a loose rock dam 7 feet high which diverts the water into a canal, several hundred feet in length, to the mill. In this mill is installed a 48 inch Leffel turbine of 60 horsepower capacity, operating under an eleven foot head. The turbine is belt-connected to the machinery of the mill which operates intermittantly. There is no steam auxiliary power since the water is sufficient at all times.

The four developments represent the extent of the used power on the main river, including the North Branch. In addition to this utilized power development, there are three other developments on the other two branches.

Rochester,- The Rochester Milling Company has a flour mill which utilizes an average head of 8 feet. The horsepower developed averages 20 with the addition of a steam auxiliary

power, since the water supply is insufficient.

Rochester,- (One mile below the Town) The Zumbro Feed Milling Company utilizes a head of 10 feet from which an average of 80 horsepower is developed.

Oronoco,- The Oronoco Mills have a timber dam of crib construction developing a 15 foot head. The dam backs the water upstream to what is known as Lake Shady, a natural reservoir 2 miles long and 500mfeet wide. In the flume are located two 36 inch and one 40 inch Stour Mills Temple turbines, developing an average of 150 horsepower.

This is a brief description of the developed water power on the Zumbro River.

FEASIBLE UNDEVELOPED WATER POWER SITES

After determining the conditions of the developed power, the manner of operation, and the amount of power,- or the quantity of water required, the next step to be taken in the investigation is the location of the feasible undeveloped sites, and the location of one site which will in no way interfere with the existing companies, and yet have power enough to be practical

An enginering company engaged to develop power on the Zumbro, would survey the basin at points theydeemed feasible. The main requirement of a site is considerable drop in a short length of stream. At these feasible points gaging stations would be set up. The purpose of these gaging stations will be explained in following discussion.

Since this course of proceedure is carred out in detail

by the United States Geological Survey, and in many instances the state geologocal survey, such data may be obtained from their reports. In this case it is impossible to make the surveys, and therefore, all information forming a part of this paper was taken from some source of this nature. The information ccncerning the present sites and the feasible sites has been obtained from the " Report of Water Resources Investigation of Minnesota " by the State Drainage Commision in 1911-1912, and from the United States Geological Survey Reports.

Although the Zumbro river flows through very narrow valleys with steep sides, it is almost impossible to develop a high head for large power sites on account of the Zumbro Branch of the Chicago Milwaukee and St. Paul Railroad which runs through the valley at a comparatively low level.

The following sites have been reported as feasible:-

Zumbro Falls
In section 17 T 109 N, R 13 W
In section 28 T 109 N, R 13 W
In section 9 T 109 N, R 12 W
In section 27 T 109 N, R 14 W.

The foregoing summary is a brief statement of the information available to an engineer engaged in water power development. The following portion of this thesis will deal with some of the problems encountered by the engineer, and the method of solving the same.

CHAPTER II

STREAM FLOW INVESTIGATIONS

CHAPTER II

Stream Flow Investigations

The most important feature in the development of water power projects, is the amount of water which may be reled upon for twenty-four hours in the day and three hundred and sixty-five days in the year. To design a plant without sufficient power to drive the machinery at all times is a needless expenditure of money, unless at times of insufficient water supply, steam auxiliary power is added. In this project upon which the thesis is based, the maximum power available at any one point, will be that amount which may be developed from the river.

There are two factors which govern the quantity of water flowing in a river at a certain point,- the amount of water falling upon drainage areas above the point, and the amount of water absorbed in some other manner than the stream flow of the river. Thus it is necessary that the area drained by the section of the river above the site, be investigated for conditions relative to these two conditions.

Perhaps the data which is the easiest to obtain is that of rainfall upon the drainage area. Stations for the purpose of measuring the amount of rainfall, in fractions of inches, which is deposited upon the section surrounding the station have been established by the Department of Agriculture of the United States, of which the Weather Bureau is a department. This,data in many cases is complete back as far as the establishment of the towns in which the station is located. The readongs taken by these stations are measurements to the nearest hundredth

of an inch of the of rain deposited upon the drainage area in the immediate vicinity of the station. These records are kept by daily readings and are accurate.

For this project, there is data of the daily rainfall for Fairbault, Rice County, Read's Landing, Winona County, Winona Winona County, Rochester, Olmstead County, and West Concord. A record of this data for the year 1910 will be found in Chapter IV.

In addition to this information, there is another source of information in the shape of Total Monthly Rainfall Reports of the U. S. G. S. In this data the individual readings are summed up for the month. A set of records for Winona, Winona County, Wabasha, Wabasha County, Blooming Prairie, Steel County, and Zumbrota, Goodhue County will be found in Chapter IV.

With this information of the precipitation, as rainfall is called, a very good idea may be obtained in regards to the amount of water which will fall upon the drainage area for a period of time equal to the extent of the data. In this particular instance the information extends back as far as 1885 for the station located at Winona, and is complete up to date with the exceptions of the years 1889, to 1892 inclusive: back as far as the year 1888 in Wabasha records, with the exceptions of the years 1889, to 1891 inclusive, and complete up to the year 1908: back to the year 1891 in the records of Blooming Prairie and complete to the year 1904: and back to the year 1893 from the records of Zumbrota with complete data to the present date with the the exceptions of the years 1898 to 1902 inclusive. Thus the record

is complete from the year to the present date.

From this data the important point to be determined is the average rainfall per month over the entire basin, and if it can be assumed that these stations set by the Weather Bureau represent a fairly good average of the variation of rainfall in the basin, the average of these total monthly rainfall records will give an average of the amount of water precipitated over the entire basin during the month for which the data was taken. In every case where there were records for more than one station, an average of the number of stations was taken. A complete average of the monthly rainfall will be found in Chapter IV.

It would be an easy matter from such data to determine the total amounts of rainfall for the individual years by the addition of the monthly rainfall, and from this calculation to show the year having the minimum quantity of water deposited on the area. This direct comparison is unsatisfactory, for the reason that it does not embody a system that is self evident. For a more perfect representation of the condition of rainfall in the basin graphs of the average monthly rainfall will be found in Plates I & II, where each separate graph represents a year's rainfall with months as abscissae and rainfall in inches as ordinates. This method of representation shows at a glance the condition of precipitation for any period under investigation. It will be observed that the year 1910 is the year in which a minimum amount of rain fell. For power development the minumum amount of water falling on a given area limits the size of the plant to be de-

signed as will be shown in latter discussion

Although a certain amount of rain reached the river basin during any certain year, the quantity that fell is no indication that the same amount will find its way into the river. There are many factors which determine the amount of rainfall passing any point in the latter state of river water, and the most important may very clearly be summed up in the following items below :-

1 Precipitation
2 Temperature
3 Topography
4 Geology
5 Surface condition
6 Natural storage
7 Shape and size of basin
8 Gradient and tributary arrangement
9 Artificial use
10 Artificial control
11 Normal wind
12 Ice formation (if any)
13 Evaporation
14 Change in channel

There has been quite a discussion for some time past on the question of the relation between the amount of water falling on a given water shed and the amount that finally reaches the river's course. One of the members of the United States Geologi-

cal Survey, Mr. C. C. Vermuele, states that there is a relation and has advanced the following formula:-

$$E = (15.50 \quad 0.16 R) (0.05 T - 1.48)$$

in which E represents all the losses on the drainage area, R the annual rainfall, and T the mean annual temperature. Although this particular equation is applicable to one river, the form, with a change in constants, may be applied to any stream. This is the idea of the originator. Just what merits the equation has will not be discussed in this thesis.

At any rate, there is quite a considerable difference in the two quantities, rainfall and run-off, and this difference is generally known as the retention of the drainage area. The method of determining this retention will be discussed in a later paragraph.

It is necessary to know something concerning the amount of water reuuing from any drainage area before any concise and accurate statement of the power available may be made. Also to determine the retention spoken above the amount of water flowing at any point must be determined. For this measurement of stream flow, the government and a majority of the states maintain what are known as gaging stations. The porpose of such a station is to determine in some unit of volume, generally the cubic foot per second, the amount of water flowing past the station for each day of a year.

These stations vary in equipment from a small and complete hydraulic laboratory equipped with weirs, current meters, and other apparatus, to a station consisting of a graduated board

or a length of link chain. For this project the following data of the station at Zumbro Falls is obtainable:-

*"LOCATION.- At the highway bridge at Zumbro Falls about 8 miles below the mouth of South Branch

"RECORDS AVAILABLE.- Since June 1909 to December 31,1912

" DRAINAGE AREA.- 1120 square miles.

"GAGE.- Chain, attached to bridge, datum unchanged since establishing

"CHANNEL.- Somewhat shifting

" DISCHARGE MEASURMENTS.- Made from bridge

"REGULATION.- The nearest dam is at Jarretts, but on account of the fall of the river, the station is above its influence. The effects of the dams above the station is not felt.

"WINTER FLOW.- Owing to the presence of rapids a short distance below and above the station and also of springs, open water is practically continuous througout the winter, from the rapids to a distance several miles downstream. A discharge measurement in February 1910 gave a result of about 15 percent less than was indicated by the open season curve. However, owing to the manner in which the measurement was made , the descrepance is largely due to the freezing of the meter. Estimates of flow for the winter months have been made by reducing the open season rating for corresponding

gage heights by 5 to 10 percent

" MAXIMUM FLOW.- The high water of June, 1908, is marked by a spike in a telegraph pole near the railroad station at Zumbro Falls. This is at an elevation of 26.7 feet above the datum plane of the gage. The highwater of April, 1888 reached a stage approximately 29.7 feet as shown by a mark not so well defined as that of the 1908 flood.

" ACCURACY.- Conditions at this station are good and therefore the records of the flow should be reliable"

*(Note:- The preceeding data was taken from, " The Report of Water Resources Investigation of Minnesota" For reference see page 10.)

In Chapter IV, are the results of the measurements of the station. These readings, as represented in this thesis, are the actual readings divided by the number of square miles drainage area. Thus the flow is in cubic feet per second per square mile.

As with the rainfall data, a comparison of the run-off for the different years is difficult to imagine from the data and for this reason on Plates III, IV, V, & VI, will be found a graphical representation of the daily run-off of the Zumbro River at Zumbro Falls, with the days of the year as abscissae, and cubic feet per second per square mile as ordinates. These curves are known as hydrographs and will be useful in determining the amount of power available, the method of which will be discus-

sed in Chapter III.

From these hydrograps another set of curves may be determined, showing the number of days in a year a certain amount of run-off may be relied upon. The axes of this set of curves, called duration curves, are the same as the axes of the hydrographs.

Suppose a line parallel to the abscissae be drawn touching the lowest point on the hydrograph. This discharge of the river will be equalled every day innthe year since it is the lowest. This is the starting point of the curve, the value of which for example, is 0.1 cubic feet per second per square mile for the year 1912. Then for 365 days in 1912 there will be at least an equal amount of discharge or a greater. If the abscissae of the duration curve were to be marked from the 0 ordinate as follows, 365, 364,.............. 0, a glance at the curve of this nature will determine the nature of the duration of any discharge. By drawing other lines similar to the first one through the point 0.1 cubic feet per second per square mile, other points of the curve will be determined and a continuous curve through the series of points is the duration curve for that year. On plate VII will be found duration curves for the years 1909 to 1912 inclusive.

Now the precipitation for the low year and the run-off for the same year have been determined. The difference between the two has been pointed out as the retention, and a curve showing the relation between precipitation, the run-off and their difference, the retention, is called a mass diagram.

The construction of such a diagram is as outlined in the following description. Suppose the average daily precipitation in inches, during the low year, were determined through out the entire drainage area and added; then the amount of rain falling on each day could be shown, and the amount of rain fallen up to any day could be determined up to the last day of the year. A table of this data taken from the United States Climatographical reports is prepared in Chapter IV.

To complete this diagram, it is necessary to adopt a similar manner of showing the run-off in terms of inches of water on the drainage area. This is done by multiplying the run-off data from the Zumbro Falls gagaing station by the number of seconds in a day and the number of inches in a foot, and by dividing this product by of the number of square feet in a mile as follows:-

$$K = \frac{60 \times 60 \times 24 \times 12}{5280 \times 5280} = 0.0372$$

This constant multiplied into the number of cubic feet per second per square mile will reduce the run-off to units of the rainfall. An addative run-off similar to the addative precipitation together with the daily run-off will be found in Chapter IV

If curves be plotted between these two addative amounts with scales of inches as ordinates and days of the year as abscissae, as shown on plate VIII, and the difference between the two curves plotted, a mass diagram will be constructed.

This analysis of the conditions of the water shed completes the study of the stream flow

CHAPTER III

SELECTION OF DAM SITE

COMPUTATIONS FOR MAXIMUM HEAD AVAILABLE

DESIGN OF COMPLETE DAM AND POWER HOUSE

CHAPTER III

The Selection of the Dam Site

The selection of the dam site of a water power project should be made with due regard to the drainage area, to the length of dam, to the minimum flood lands, and hence minimum damage to property, to the foundations of the constructions, and to the reservoir capacity

One of the most important features in the selection of a dam site on the Zumbro, is the matter of damage to property by the back water. In all water power projects, the development of the greatest head is generally the one important feature in a small stream's power, a stream where the flow at times in the year is limited. Since in any case, the power develpped is proportional to the amount of water flowing and the distance through which it falls, in a small stream, the development of a large head is important.

The Zumbro Branch of the Chicago Milwaukee and St. Paul Railroad follows the course of the river throughout almost the entire length of the main stream. The difference between the elevations of the river and the track varies at different points, and hence the site which will develop the highest head with the largest drainage area, will be practically the only solution of the problem, provided the distance between two similar points on the two opposite banks, the points marking the height of the head water, are not too far apart, thus making the length of dam required too great for economical construction.

After a careful survey of the maps of the drainage area, it was concluded that the erection of a plant at Zumbro Falls would be the practical solution for the following reasons:

1 Maximum drainage area

2 Maximum head above the area

3 Narrowness of the stream and the natural bluffs as shown by the converging contours(See Plate IX)

4 Minimum amount of flood land

5 Fairly good fall to tail water to relieve flood conditions

The above considerations are made more evident by an inspection of the map of the Zumbro River in this locality, as shown by plate IX, in which is shown the area flooded up to the level of the 850 foot contour. The location of the dam site, just above the villiage of Zumbro Falls, does not require the demolishing or the moving of any of the houses. In fact the greater part of the land to be flooded is unsettled. The cultivated land at the 53 mile point, just below the junction of the North and South Branches, would be practically inundated by the rise of the water to the 850 ft. contour, and provision for the lease or the purchase outright of this and similar lands will have to be made to render possible the use of this site at Zumbro Falls.

No state or county highways will be interfered with as the only crossing is at Zumbro Falls, where a highway bridge crosses the stream. (See Plate X) Since the dam of this pro-

posed plant is to be located above this bridge, the latter would be subjected to no grave dangers than are attended at maximum flood conditions.of the stream in its natural course. The branch of the road, shown dotted in fromt of the dam has no apparent use or destination, and will not offer any difficulty to the flooding of its extremity. The road running parallel to the stream on the north bank is well above the 850 ft. contour and hence safe.

In the case of the Zumbro Branch of the Chicago, Milwauke and St. Paul Railroad, however, there are places where arrangements must be made for the protection of the railway right-of-way. If the points are picked out from Plate X in a course proceeding from the dam upstream, they will be as follows:-

(a) At the 47 mile point the tracks cross a creek and evidently this creek drains considerable land. It is reasonable to assume that there is already a large culvert or a small bridge erected; or where would this drainage water go if the earthern embankment extended across the channel of the creek? Furthermore, it is reasonable to assume that the railroad is upon an embankment, for the laying of the railroad roadbed on the flat ground near the river's level, would invite disaster from floods. Wherever the base of the rail is not at an elevation of 855.00 ft., it will be necessary to build up the embankment to satisfy this condition. It will also be necessary to riprap or otherwise protect the roadbed, according to the wishes of the Chicago Milwauke and St. Paul Railroad; all embankments exposed to the waters of the river up to the 850 ft. contour.

(b) An exactly similar case is that of a gulch shown by the converging contours of the northeast bank between the 49 and 50 mile points. Here another culvert or bridge of some description must be installed if no provision for the same has been found, or if the present provisions are deemed inadequate toward meeting conditions subsequent upon the rising of the water to the 850 ft. contour.

(c) Between the 50 and 51 mile points there is a similar condition and must be met in the same manner.

In all of the preceeding cases it is quite likely that the present bridges or other accomodations for letting the water through the embankment will have to be raised and enlarged. The actual conditions can only be ascertained by further and more es extensive surveys of the localities in question where the 850 ft contour lies on the other side of the road, showing that the railway embankment will have to act as an earthern dam. It may be necessary to strengthen these places in order to be safe.

These conditions as outlined above have been found to be a source of minimum cost as compared with the other possible dam sites, the data and description of which are not herein included. Other conditons may arise to render this site more difficult to develop than is now our present opinion. These exigencies, however are likely to happen should any of the other sites be selected and cannot be taken into account without more detalied data.

The remainder of this thesis will, therefore, be devoted to the consideration of the project at Zumbro Falls.

Computations For Power

On the following page will be shown the computations used to determine the average head through which the water would act. The pondage will be taken between the 850 ft. and the 840 ft. contours, without allowing the water to fall below the 840 ft. contour, as is shown in the subsequent design of the dam. The elevation of the tail water below the dam will be taken as 820 ft. This is shown to be true to existing conditions at the site (Plate IX) Thus, the maximum head is the difference between the highest and lowest contours, 850-820 equals 30 ft. If this water is drawn down to 840 ft. the head becomes 20 ft. It is obvious , since the surface area at the 850 ft. contour is greater than that at the 840 ft. contour, the average head which will be used in this thesis will be nearer 850-820 = 30 ft. than 840 - 820 = 20 ft. To find the average head the volume of water contained in each foot of depth is multiplied by the distance of the center of gravity of that section (one foot thick) from the reference line, here taken as the 840 ft. contour. From principles in mechanics, the sum of the moments of the volumes contained in the the area 850 - 840 divided by the total volume of water in the section 850-840, will give the moment arm to the center of gravity of the whole section.

Area on the 850 ft. contour	=	29,200,000 sq.ft.
Area on the 840 ft. contour	=	9,520,000 sq. ft.
Difference	=	19,680,000 sq. ft.

The gain in pondage per one foot rise from 840 ft. contour to 850 ft. contour is equal to :-

19,680,000 / 10 = 1,968,000 sq. ft.

The area on 850 contour 29,200,000 sq. ft.

The area on 840 contour 9,520,000 sq. ft.

Average area 19,360,000 sq. ft.

Height of section = 10 ft.

Total volume = 193,600,000 cubic ft.

Contour	Area	Average	C.G.	Moment
840	9,520,000			
		10,504,000	0.5	5,252,000
841	11,488,000			
		12,472,000	1.5	18,800,000
842	13,456,000			
		14,440,000	2.5	36,800,000
843	15,424,000			
		16,408,000	3.5	57,400,000
844	17,392,000			
		18,376,000	4.5	82,500,000
845	19,360,000			
		20,344,000	5.5	111,700,000
846	21,328,000			
		22,312,000	6.5	145,000,000
847	23,296,000			
		24,280,000	7.5	181,500,000
848	25,264,000			
		26,248,000	8.5	225,500,000
849	27,232,000			
		28,216,000	9.5	268,000,000
850	29,200,000			
		Total		1,131,952,000

Average head $= \frac{1,131,952,000}{193,600,000} =$ 6.82 above 840 ft.

Thus it is shown the average head above the 840 contour is equal to 6.82 ft. Add this to the difference in the minimum head (840 - 820 = 20) and the total average head above the tail water is 26.82 ft.

The fundamental equation for horse power is:-

$$\text{H. P.} = \frac{\text{cu. ft./sec.} \times \text{ave.head} \times W}{550}$$

where W is the weight of a cubic foot of water. To reduce this to horse power hours, it is necessary to divide the above equation by the number seconds in an hour, 3600. Then the horse power hours at any head and for any quantity of discharge may be determined.

Application of this formula to the conditions of this case gives:-

$$\frac{193,600,000 \times 62.5 \times 26.82}{1,980,000} = 163,800$$

This formula cones from the principle that a mass of W pounds passing through a distance x will do Wx foot pounds of work per unit time, and may be reduced to horsepower by dividing the number of foot pounds of work per second by 550

Now in one mothh there are 30 x 24 or 720 hours, and hence the continuous horsepower is equal to 163,800 horsepower hours divided by 720 hours or 227 continuous horsepower. which may be used for one month starting with a reservoir full Similarly for a half a month there may be developed 2 x 227 or 454 horsepower, or for 2 months there may be developed ½ 227 or 113 horsepower.

Plates III and IV show the discharge of the river at Zumbro Falls for the lowest years on record, 1911 and 1912. In Plate XVIII, the drainage area of the river is shown in dotted lines, The ares which is drained above, the water from which passes by the cross section of the site at Zumbro Falls, is 1120 square miles. The horsepower available may be computed by another form of the preceeding formula. Using 80 percent efficiency at the turbine shaft, the equation reduces to:-

$$\text{H. P.} = \frac{\text{Sec. Ft. x Head x 0.8}}{8.8}$$

which for the values of this particular case is :-

$$\text{H. P.} = \frac{0.2 \times 30 \times 1120}{11}$$

The factor of the weight of water per cubic foot, and the conversion factor are taken up in the constant 8.8, while the 0.2 sec. ft. was obtained from the scale of discharge charts In this manner the ordinates for the right hand collum of Plates III, IV, V, & VI, were obtained.

Several trials for a balance between the points where the low water could be charged againse the reservoir capacity resulted in the value of 480 continuous horsepower at the turbine shaft. The abscissae of these charts are in time, one inch horizontally being equal to 20 days, and one inch vertically equals 610 horsepower, and thus 610 x 20 x 24 = 293,232 horsepower hours as the value of one square inch. The available horsepower storage capacity is 163,800; then :-

$$163{,}800 \;/\; 293{,}232 = 0.56 \text{ square inches}$$

This means that in no case should the cross-hatched area be greater than 0.56 sq. in. From careful planimitering and checking on the number of squares included, the greatest area in the shaded portion is 0.485. These extremely low periods being taken into consideration, there is a good factor of safety for the larger part of the time, as the water is usually higher in the reservoir, and the discharge is greater.

Thus the conclusion to be drawn from the foregoing calculations is that it is not feasible to develop more than 480 horsepower, but such a development would be safe for continuous operation. The following portions of the thesis will treat with the design of a plant to supply the calculated power.

Design of Substructures

The dam is to be so constructed that the waters at an elevation of 850 Ft. will be held back in storage. When the flood tends to rise above that mark, the tainter gates will be opened to allow the water to pass through and over the spillway to relieve the head. Since there is to be no overflow in the construction of the dam to be builded, except through the tainter gates, the dam, proper will be of the retaining wall type. The computations are as follows:-

Dam Plate XI- Retaining wall type; shape of section weight of section, center of pressure, at both toe and heel were computed from " A Treatise on Masonry Construction " by Prof. Ira O Baker. The formulae are standard in all engineer-

ing practise and need not be given here. Plate XI shows the type, shape, dimensions, and pressure diagrams of the dam.

Tainter Gate & Spillway Plate XIII- The maximum discharge of the river occurred on May 19, 1912(as far as the records available show) at which time the discahrge was 5.24 cubic feet per second per square mile. The drainage area is 1120 square miles, and with a total factor of safety of 2 the discharge will equal:-

$$1120 \times 2 \times 5.24 = 11,737.6 \text{ sec. ft.},$$

a value which will be considered 12,000 sec. ft. as the maximum discharge of the river at any time . The design then will be for enough tainter gates to accomodate the floods that may be reasonable expected. Assume an adopted length of 13 ft. of spillway as shown " out to out " of piers in Plate XII. The opening between the piers forms a wier 13 ft. long = l. Since the water is drawn down to an elevation of 840, the crest of the weir and hence the spillway will be at 840 ft. The head on the weir will equal 840 - 850 = 10 ft. = h.

From Franis Formula the equation:-

$$q = 3.33\, lh^{3/2}$$

is derived, where 3.33 is an experimentally derived constant in standard use. Then:-

$$Q = 3.33 \times 13 \times 10^{3/2} = 1,368 \text{ sec ft.}$$

which is the discharge of one gate, and hence, since there must be discharged 12000 sec. ft. the number needed will be:-

$$12,000/1368 = 8.8 \text{ gates}$$

for which we will use 9 gates.

The discharge per gate will be 12,000 / 9 = 1,333 sec. ft. The discharge is equal to the area of the channel multiplied by the velocity and hence the velocity must equal 1,333 / 10 x 13 or 10.25 ft. per sec., a velocity representing the horizontal component of the water. This velocity is constant. After passing the crest of the weir the water has also a vertical component of velocity due to gravity. From mechanics it may be concluded that the water will travel 10.25 ft. per sec. horizontally and a distance equal to ½ x 32.2 x t^2 vertically, t being the time in seconds and 32.2 the acceleration per second due to gravity. By solving this equation by the substitution of different values of time the following table has been prepared.

Velocity Curve Data

"t" Sec.	Hor. Dist.	Vert. Dist.
0.2	2,05	0.644
0.4	4.10	2.570
0.6	6.15	5.800
0.8	8.20	10.300
1.0	10.255	16.100

This curve is shown in Plate XIII, and would be the natural course of the water if allowed to pass over a sharp crested weir. The adopted circular curve insures the flow of water in contact with the section and permits of no vacuum. This is a desirable feature in stream flow curve design since a vacuum produces a bad effect on the flow of the water, and causes eddies which tend to undermine the foundation and thus cause wash-outs. The earth pressures were obtained in a manner explained for the re-

taining wall section with 10 ft. head on the crest.

Pier Section Plate XII- This section was computed in a manner similar to the Dam Section in accordance with Baker and D. W. Mead's " Water Power Engineering "

Abuttment - This abutment was designed according to standard engineering practice from the references given above.

Miscellaneous - Log sluces, fish ladder are designed conforming to laws and designs governing water power development and the details will not be herein included.

Machinery for gate operation - This part of the power development is apart from the purposes of the thesis and would be separately considered in any investigation of this nature; therefore, it will not herein be included.

From the graphical solution of the forces acting on the various sections of the design, Plates XI, XII, and XIII, the designs are shown to be safe, and as is usual practice, the resultant of the forces in all cases lies within the middle third of the section. This signifies that there is no tension at any point of the base.

Selection of Turbine Units

In selecting a water turbine to be used in connection with an alternating current generator, there must be a balance between the number of poles on the generator, the speed at which the unit is to operate, the power to be supplied and the efficiency of the unit.

Suppose in this instance a 24 pole, 60 cycles, 2300 volts three phase generator is selected. The speed of this gen-

erator to produce a voltage of 60 cycles frequency must be such, that it conforms to the following:-

$$S = \frac{\text{Frequency of magnetic field}}{\frac{1}{2}\text{ Number of poles}}$$

or the speed equals:-

$$\frac{60 \times 60}{\frac{1}{2} \times 24} = 300 \text{ R. P. M.}$$

In order that the speed shall be constant, the turbine shall be so selected the econimical speed shall be 300 R. P. M.

To insure that constant operation shall be a feature of the plant, it will be necessary te select two turbines, each of the same size. Since the total power to be developed is 480 H. P. each turbine must be capable of producing 240 H. P. Suppose that an equation be set up between power, speed and head under which the unit is tomoperate. The equation will have the following form:

$$* \; P = \frac{K_5 \times h^{5/2}}{n^2}$$

where K_5 is the speed constant of the turbine, P is the the power in horse power, h is the head, and n is the R. P. M. By substituting the proper values for this case in the equation, the following value is obtained

$$* \; K_5 = \frac{300 \times 300 \times 240}{30^{5/2}} = 4400$$

If it is supposed that this is the proper solution to the case under discussion, all that is necessary to determine the turbine selection will be a set pf curves plotted between the speed coefficient " K_5 " and efficiency. There is a set of

(*) See D. W. Mead's " Water Power Engineering "

curves for three turbines which pass through the value of 4400. Thus since the operation is within an efficient range it may be assumed that any of these three will satisfy the conditions required by the turbine.

It is evident from the foregoing discussion that there has been no balance established, but for example, let the turbine corresponding to curve No. 1 be selected, This is a characteristic curve for a Wellman Seaver Morgan Co. Turbine, and since of the three curves it has a maximum efficiency at approximately 4400, it will be concluded that it is the correct turbine.

To specify the turbine it is necessary to know the diameter,and therefore it will be necessary to set up an equation between the diameter, the power, and the head under which the turbine is to operate. The equation for the power of a turbine under such conditions will be :-

$$P = K_2 \times d^2 \times h^{3/2}$$

in which K_2 is the power constant of the turbine, d the diameter and h the head under which the turbine is to operate normally. If a curve be plotted between horsepower under one foot head for ordinates and R. P. M. under the same conditions for abscissae, for any size of turbine of this type, all other similar turbines of different character of power and speed should have similar and proportional curves, if due regard be paid to the diameter of the turbine under discussion. To find this K_2 (see K_5 p. 33) a curve for this particular type of turbine must be obtained from test data. On Plate XVI a series of these curves have been obtained from Hoyloke tests of this type of turbine while tested under dif

ferent gate openings. The horse power of this turbine is about 1.58 under efficient operation at one foot head. This is to say that delivering 1.58 H. P. under these condtitions the turbine is working at its best, althoughit may deliver more power, it will be less efficient. Then it may be decided that this is the value from which K_2 is to be determined. Taking this value and dividing it by the square of the diameter a value of :-

$$1.58 / 24 \times 24 = K_2 = 0.00262$$

In the actual determining the curves from which this data was taken were drawn for a 30 inch turbine and the corresponding scale was changed after all calculations for the size of the turbine were made.

While this power coefficient is being so discussed it is possible to show that the turbine selected will deliver the actual power required by an interpretation of the curve. Since the equation for the power constant does not involve the speed, and since the curves are drawn between the power and speed under one foot head a simple multiplication of the value from the curve by the three-halves power of the head, the total horsepower will be given Thus:-

$$\text{H. P. 30 Ft. head} = 1.58 \times 30^{3/2} = 250$$

Checking against the equation for the power constant to show that the selection of the turbine is correct the result is:-

$$0.00262 = \frac{240 \text{ H. P.}}{D^2 \times 30^{3/2}}$$

or the diameter, $D = 24.3$ inches.

The diameter for all practical purposes will be 24 inches, and the assumptions made in foregoing discussion that a 24 inch turbine is to be used is justified from this solution

This justification of the selection of the proper diameter does not justify the selection of the turbine with the foregoing characteristics, because the indicated operation under the range of heads for the project will in many times be inefficient. It must now be determined whether the turbine is operating under an efficient condition of speed through out the range of heads.

For this purpose it is necessary to investigate the turbine from the standpoint of efficiency and speed. Suppose an equation be set up between diameter and head under varying speeds. Then :-

$$\text{Delta} = \frac{D\ N}{H^{\frac{1}{2}}}$$

where the values of the symbols are as before, and Delta represents a constant for all types of wheels under similar circumstance and of the same design.

Since the turbine is to operate under heads ranging from 20 ft. to 30 ft., this constant will have two efficient values, which when the value of head, 20 ft. and 30 ft., and the values of the diameter and speeds are substituted , are 1660 and 1350 respectively

On Plate XVI, there are curves of this constant plotted against efficient operation for different gate openings. It will be seen that the machine, if operating at full gate opening, the

efficiency of the unit on the 20 ft. head will be 67 percent, but since the turbine may be overgated this efficiency may be brought up to 75.5 percent, which under such extememe conditions of low water will satisfy requirements. Under the normal operating conditions with the full gate opening at 30 ft. head, the efficiency will be 82.5 percent. Thus the selection of the turbine is justified from all standpoints, and it was only selected after several other types and makes had been investigated along the same lines. In all cases this turbine was the most satisfactory.

The quantity of water to be supplied to this turbine is determined from the following equation:-

$$K = q \,/\, D^2 h^{3/2}$$

This equation with a value for the constant will be found on page 339 of D. W. Mead's Water Power Engineering. Solving the above, a discharge of 61 sec. ft. was required, necesitating an area of penstock of 1.49 sq. ft. Since an iron pipe type of penstock was to be used in this design, owing to the small power to be developed, a diameter of approximately 2 ft. is required.

The selection of the generators, transformers, switchboards, lightining arresters, etc. will not be gone into in this paper

It will be impossible to design a complete power house and consequently only a sketch of the layout of the power house showing the arrangements of apparatus and machinery will be shown in Plate XVII. This completes the design to be treated with in this thesis

CONCLUSION

In conclusion we wish to state that, from an engineering standpoint the development of any power site along the Zumbro River would be a failure. From the fact that the project under discussion is a failure, and since this project was the most advantageous of any site, any other site, not being a practical solution of the problem, would be a failure. This failure is based on the reconing in dollars and cents income as interest on an investment

It will be necessary to go into the cost data of the plant to show this fact, since by working from the point of income it can be shown that there will not be enough return to warrant such an expenditure of money as this plant would require.

It will be assumed that the power developed is to be used for lighting, no electric power to be supplied, and that the plant be operated on a 30 percent load factor (for the city of Madison Wisconsin this load factor is averaged by 29 percent and hence a town of the size of Zumbro Falls less than 1000 population would not have as large a load factor) which is high, but will be used to make the proposition as feasible as possible. If this power were to be sold at 10¢ per K. W. Hr. a basis for the income may be made.

Total K. W. H.r. per day = 24 x 0.30 x 480 = 3460

Total income per year = 3460 x 0.10 x 365 = $12,650

This income per year represents the income on the investment of the plant, an investment which must be feasible.

Suppose interest allowed is 6 per cent, taxes 1.5 percent, depreciation 8 percent, maintenance, overhead charges, op-

erating charges, including salries, 15 percent, be a fair estimate of the interest or percentage of the investment is to represent. Then $ 12,650 is 30.5 percent of the investment without any gain upon the project, or, the maximum amount of money that could be expended upon this projest is $ 42,500

In the above discussion there has been nothing stated of the cost of a transmission system which would be used in the distribution of power to the customers. If the cost of the same including secondary mains and transformers be placed at $ 2000 per mile, and if there are to be five miles of such transmission to and in the town, there remains only $ 32,500 to be invested in the plant itself, and the meters for the customers.

If the power house itself cost as much as an ordinary brick dwelling $ 15,000, there will be $ 17,500 left for the remaining construction. There are nearly 20,000,000 square feet of land to be submerged and utilized for the power development. With the remaining money there must be expended, at a low price of 10 dollars an acre, $ 5000 for flood lands.

If the engineer on the work is to receive approximately 5 percent of the cost, $ 2100 , there remain only about $ 10,000 to buy the machinery, build the dam and settle the law suits. Therefore we conclude that the problem is not practical

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TOTAL MONTHLY RAINFALL FOR

Winona, Winona County, Minnesota

Year	J	F	Mr	Ap	My	Ju	Jy	Au	S	O	N	D
1885											0.70	1.93
1886	5.60	0.45	1.65	1.80	1.30	2.40	2.40	4.60	4.55	1.70	1.60	0.42
1887	0.50	1.16	0.25	1.62	0.50					0.68	0.35	
1888	1.00		2.40									
1893	1.35	2.20	2.19	4.31	2.88	1.60	3.33	1.31	2.30	2.84	1.42	2.46
1894	1.14	0.58	2.11	4.57	4.21	4.17	1.27	0.02	1.93	2.27	1.50	0.86
1895	0.92	0.61	0.54	2.25	6.67	4.32	2.67	2.71	5.31	0.51	1.29	1.55
1896	.37	0.37	1.35	6.41	4.60	5.35	1.83	2.27	3.19	2.99	3.08	0.53
1897	2.01	1.00	1.71	2.35	2.90	5.97	4.79	3.46	0.68	0.81	0.53	0.78
1898	0.67	0.91	1.64	2.98	2.10	2.72	2.39	2.55	0.88	4.64	1.96	0.21
1899	1.00	1.09	2.47	1.24	3.35	14.4	1.49	4.70	1.28	1.05	0.47	1.38
1900	0.58	1.00	1.37	1.84	1.65	2.20	13.2	1.99				
1901												
1902	0.70	0.83	0.89	1.68	9.19	4.29	6.67	2.92	1.46	1.77	2.09	2.46
1903	0.07	1.42	2.55	3.28	9.55	2.00	3.76	6.56	4.45	1.87	0.02	0.57
1904	0.26	0.53	1.70	1.52	4.40	3.91	2.16	1.91	4.42	2.91	0.26	1.05
1905	0.57	1.05	1.72	0.45	7.89	6.46	2.63	5.75	1.77	2.17	2.20	0.59
1906	1.23	0.35	2.50	1.16	6.17	2.44	4.06	3.80	5.49	2.19	1.13	0.94
1907	1.01	0.28	1.77	1.47	1.76	2.66	4.37	6.80	6.15	0.80	1.37	0.74
1908	0.43	1.35	1.67	2.63	7.10	7.08	2.58	1.65	2.62	2.88	0.29	1.21
1909	1.53	1.68	1.15	4.28	2.20	2.67	0.50	7.16	4.66	1.24	5.49	1.52
1910	1.07	0.14	0.02	1.20	2.98	0.25	0.62	4.24	3.94	0.87	0.44	0.43
1911	0.93	0.98	0.81		4.02	4.91	2.08	3.67	2.90	7.54	1.17	1.63
1912	0.52	0.28	1.01	2.48	6.20	1.51	6.14	3.05	3.61	1.80	0.73	1.45

TOTAL MONTHLY RAINFALL FOR

Wabasha, Wabasha County, Minnesota

Year	J	F	Mr	Ap	My	Ju	Jy	Au	S	O	N	D
1888	1.25	0.60	2.15	2.80	8.25	2.05	2.55	2,30	1.15			
1892							4.54	1.83	2.30	1.87	0.78	1.13
1893	1.70	3.08	2.93	4.66	2.32	1.61	2.13	2.28	2.00	2.59	1.06	4.08
1894	1.09	0.35	1.29	4.39	5.06	2.64	0.18	0.18	2.61	2.98	0.85	0.93
1895	1.50	0.84	0.50	1.95	3.10	5.09	5.71	2.19	4.42	0.40	2.39	0.69
1896	0.93	0.22	1.83	6.58	3.30	3.81	0.93	1.19	3.06	3.33	3.53	0.92
1897	2.07	0.82	1.87	1.47	2.24	4.15	8.55	4.14	1.21	1.27	0.65	0.26
1898	0.26	1.36	1.35	1.92	1.79	3.08	1.24	2.40	0.72	4.81	1.58	0.60
1899	1.06	0.90	2.09	1.12	5.69	6.32	1.81	6.01	2.04	2.24	0.88	1.65
1900	0.63	1.33	1.59	2.52	1.13	1.86	8.61	3.84	6.60	9.81	0.78	0.66
1901	0.49	0.64	2.38	1.02	1.14	6.30	3.70	1.32	6.86	2.25	0.90	0.66
1902	0.75	0.67	0.85	2.22	8.22	6.43	6.87	3.08	2.86	3.27	3.27	2.31
1903	0.26	1.10	1.93	2.63	8.67	2.21	4.45	4.09	9.77	1.75	0.22	0.76
1904	0.23	1.51	1.50	1.83	2.42	4.56	2.75	2.63	2.34	4.32	0.28	1.38
1905	0.75	0.92	1.61	0.69	5.86	4.56	2.18	8.29	2.22	3.88	1.57	0.53
1906	1.83	0.45	2.15	1.61	7.30	4.45	2.47	4.24	5.07	3.35	2.38	1.30
1907	1.64	0.76	2.47	1.23	1.12	4.58	2.98	6.18	3.10	1.72	1.24	0.58
1908	0.37	1.11	1.96	3.31	6.16	9.16	4.51	1.47	2.52	2.00	0.64	0.80

TOTAL MONTHLY RAINFALL FOR

Blooming Prairie, Steel County, Minnesota

Year	J	F	Mr	Ap	My	Ju	Jy	Au	S	O	N	D
1891							1.47	1.40	1.00	1.31	0.05	2.30
1892	0.25	0.80	0.85	2.95	4.47	8.65	4.05	0.60	2.05	1.55	0.44	0.80
1893	0.95	2.53	2.49	4.50	3.15	2.75	4.00	4.15	1.20	3.05	0.65	2.50
1894	0.65	0.20	1.47	3.27	4.60	2.60	t	0.70	2.95	2.75	0.58	0.62
1895	0.50	0.25	0.37	1.10	3.35	4.25	2.60	2.50	4.65	0.25	1.65	0.25
1896	0.25	0.25	1.20	5.70	5.20	2.72	0.87	1.55	3.05	2.50	3.75	1.62
1897	1.10	0.40	1.75	1.45	0.95	5.65	9.10	4.00	0.60	1.10	0.35	0.60
1898	0.20	1.70	1.02	2.20	3.65	3.60	1.20	3.05	0.40	4.05	1.40	0.05
1899	0.35	0.95	0.90	1.55	3.45	10.3	4.10	4.00	1.10	2.35	0.75	0.70
1900	0.50	0.65	1.05	1.51	0.75	1.95	6.45	2.20	6.35	3.75	0.20	0.20
1901	0.35	0.40	2.30	1.55	1.40	5.30	1.70	1.65	9.35	0.35	0.45	0.45
1902	0.50	0.97	0.10	2.70	8.04	4.05	6.40	3.90	3.60	1.95	3.52	1.70
1903	0.55	0.70	2.30	3.65	10.0	2.20	3.80	7.55	6.90	2.35	t	1.10
1904	0.27		0.30	1.40	1.19				2.25	4.25		

Note " t " signifies less than 0.01 inches

TOTAL MONTHLY RAINFALL FOR

Zumbrota, Goodhue County, Minnseota

Year	J	F	Mr	Ap	My	Ju	Jy	Au	S	O	N	D
1893										2.00	0.80	3.58
1894	1.10	0.30	0.74	4.15	2.24	0.26	0.50	0.70	2.70	3.30	0.70	1.00
1895	0.80	0.70	0.10	1.30	1.90	5.10	2.15	1.70	2.40	0.90	1.90	0.60
1896	1.00	0.10	1.20	2.50	3.10	2.60	0.90	3.10	0.60	1.20	3.00	0.90
1897	0.40	1.70	2.40	0.90	0.70	3.70	4.50	2.70	1.10			
1903							4.53	4.49	7.17	1.95	t	
1904	0.70	0.90	0.75	1.65	2.62	8.40	4.11	2.00	2.14	5.15	t	1.68
1905	1.10	0.80	1.87	0.55	5.93	5.60	1.60	4.25	1.30	2.57	1.42	0.30
1906	1.94	t	1.25	0.86	4.92	1.05	1.81	4.80	3.58	2.13	1.49	0.53
1907	1.12	1.49	0.55	1.34	1.13	4.05	4.58	4.25	2.38	1.50	0.45	0.15
1908	0.39	0.52	1.49	4.06	5.19	8.27	2.92	1.08	1.54	4.29	0.90	1.24
1909	1.33	2.35	0.47	2.33	3.17	3.86	1.07	4.85	5.10	0.99	5.77	1.17
1910	0.87	t	0.02	0.40	2.25	0.13	1.14	3.04	3.92	0.66	0.15	0.17
1911	0.67		0.84		5.39	4.31			3.19	10.3	0.67	1.93
1912	0.51	t	0.35	2.25		3.63	4.75	5.35	1.80	1.61	1.35	1.04

Note:- "t" signifies less than 0.01 inches rainfall

Note:- Records of Mazeppa, 7 miles east, used from October 1893 to September 1897, inclusive.

AVERAGE MONTHLY RAINFALL FOR

Blooming Prairie. Wabasha, Winona, & Zumbrota

Year	J	F	Mr	Ap	My	Ju	Jy	Au	S	O	N	D
1892	0.25	0.80	0.855	2.95	4.47	8.67	4.25	1.22	2.18	1.71	0.61	0.97
1893	1.35	2.95	2.54	4.50	2.79	1.99	3.16	2.58	1.84	2.61	0.98	3.16
1894	0.99	0.37	1.40	4.10	4.03	2.34	0.48	0.40	2.57	2.82	0.91	0.85
1895	0.93	0.60	0.38	1.65	3.80	4.65	3.32	2.72	4.17	0.54	1.83	0.77
1896	0.64	0.23	1.40	5.27	4.03	3.61	1.13	2.05	2.47	2.54	3.33	0.99
1897	1.40	0.98	1.93	1.54	1.75	4.36	6.73	3.57	0.74	1.03	0.51	0.55
1898	0.36	1.32	1.34	2.37	2.51	3.13	1.61	2.67	0.67	3.50	1.88	0.29
1899	0.80	0.98	1.82	1.30	4.19	7.03	2.36	3.93	0.87	1.88	0.70	1.24
1900	0.57	0.99	1.33	1.95	1.18	2.00	2.12	2.64	6.48	6.78	0.49	4.43
1901	0.42	0.52	2.34	1.28	1.28	5.80	2.70	1.48	8.10	1.30	0.68	0.56
1902	0.65	0.82	0.61	2.20	8.38	3.71	6.50	4.58	2.71	2.19	2.96	2.16
1903	0.29	0.17	2.26	2.85	9.40	2.30	3.97	2.70	7,04	1.99	0.08	0.77
1904	0.41	0.98	1.98	1.67	3.15	5.62	3.01	2.18	2.96	4.14	0.18	1.67
1905	0.80	0.93	1.73	0.56	6.56	5.54	2.47	6.09	1.76	2.87	1.73	0.47
1906	1.70	0.27	2.30	1.21	6.13	2.65	2.78	4.24	4.71	2.22	1.61	0.93
1907	1.19	0.84	1.59	1.34	3.76	3.64	5.74	3.88	1.34	1.09	1.02	0.49
1908	0.39	0.99	1.67	3.28	6.15	8.17	3.00	1.36	2.22	3.06	0.61	1.08
1909	1.43	2.03	0.81	3.31	2.59	3.27	0.89	6.10	4.88	1.12	5.63	1.34
1910	0.87	0.07	0.02	0.08	2.61	0.19	0.58	2.64	3.93	0.76	0.34	0.30
1911	0.80	0.37	0.82		4.70	4.61	1.04	1.88	3.05	8.90	0.92	1.78
1912	0.52	0.14	0.73	2.37	3.10	2.47	5.44	4.19	2.70	1.71	1.04	1.29

DAILY RUN-OFF AT ZUMBRO FALLS IN CUBIC FEET PER SQUARE MILE

For 1909

Dy	J	F	Mr	Ap	My	Ju	Jy	Au	S	O	N	D
1							.415	.176	.216	.242	.242	.980
2							.362	.176	.216	.239	.684	.910
3							.379	.176	.216	.236	.670	.945
4							.379	.176	.216	.226	.590	1.06
5							.312	.169	.216	.226	.482	.892
6							.312	.166	.208	.226	.289	.582
7							.280	.160	.208	.223	.362	.467
8						.515	.265	.191	.208	.216	.340	.465
9						.473	.251	.199	.208	.222	.321	.465
10						.433	.251	.199	.208	.222	.321	.465
11						.454	.239	.750	.214	.272	.335	.465
12						.473	.251	1.31	.638	.356	.634	.456
13						.454	.239	1.02	.876	.295	1.14	.456
14						.397	.251	1.30	.640	.287	2.15	.456
15						.397	.234	1.50	.640	.297	3.59	.456
16						.362	.223	1.83	.522	.263	2.24	.456
17						.397	.222	1.02	.505	.248	1.58	.456
18						.537	.222	7.59	.465	.237	1.16	.447
19						.473	.227	.693	.433	.237	1.07	.467
20						.545	.222	.536	.342	.237	1.00	.482
21						.345	.214	.335	.335	.237	1.00	.504
22						.362	.193	.335	.335	.242	1.14	.490
23						.903	1.91	.397	.335	.237	.985	.467
24						.662	.197	.289	.369	.231	.827	.467

DAILY RUN-OFF AT ZUMBRO FALLS IN SECOND FEET PER SQUARE MILE

For 1909

Dy	J	F	Mr	Ap	My	Ju	Jy	Au	S	O	N	D
25						.662	.197	.289	.369	.213	.827	.467
26						.640	.191	.302	.369	.223	.810	.426
27						.573	.186	.289	.335	.222	1.34	.410
28						.537	.179	.289	.289	.213	1.70	.408
29						.514	.179	.293	.211	.211	.136	.375
30						.514	.179	.260	.159	.213	1.11	.383
31							.176	.248		.211		.392

For 1910

Dy	J	F	Mr	Ap	My	Ju	Jy	Au	S	O	N	D
1	.388	.295	.240	.454	.265	.231	.163	.134	.160	.143	.137	.140
2	.384	.305	.237	.433	.260	.226	.163	.147	.137	.143	.149	.147
3	.380	.302	.264	.433	.265	.216	.161	.147	.147	.143	.149	.153
4	.375	.284	.278	.418	.248	.219	.160	.134	.145	.143	.149	.141
5	.371	.261	.376	.379	.248	.211	.155	.134	.149	.143	.149	.147
6	.366	.273	.875	.361	.251	.216	.163	.134	.155	.143	.149	.141
7	.362	.278	2.50	.361	.248	.208	.160	.134	.155	.143	.149	.147
8	.375	.293	2.11	.357	.239	.208	.160	.134	.149	.136	.149	.121
9	.367	.282	1.91	.331	.237	.207	.161	.134	.145	.134	.147	.141
10	.362	.271	1.64	.327	.237	.207	.155	.134	.145	.134	.147	.141
11	.367	.261	1.63	,327	.231	.207	.149	.138	.147	.137	.147	.131
12	.224	.266	1.58	.321	.237	.203	.160	.143	.137	.137	.149	.134
13	.331	.255	2.05	.315	.237	.197	.157	.147	.147	.137	.143	.134
14	.308	.261	2.18	.299	.237	.195	.155	.147	.147	.134	.147	.137
15	.305	.264	1.72	.311	.234	.193	.153	.149	.147	.134	.149	.137

DAILY RUN-OFF AT ZUMBRO FALLS IN SECOND FEET PER SQUARE MILE

For 1910

Dy	J	F	Mr	Ap	My	Ju	Jy	Au	S	O	N	D
16	.308	.253	1.45	.299	.226	.188	.154	.164	.146	.134	.149	.140
17	.308	.247	1.27	.308	.290	.192	.156	.211	.145	.132	.137	.143
18	.305	.250	1.14	.299	.308	.192	.145	.206	.139	.132	.143	.140
19	.305	.247	1.07	.302	.311	.185	.149	.206	.132	.143	.157	.140
20	.320	.238	1.07	.302	.308	.173	.155	.187	.137	.147	.152	.136
21	.320	.235	1.07	.296	.310	.181	.146	.167	.134	.149	.147	.140
22	.308	.235	.980	.296	.341	.180	.146	.163	.143	.149	.141	.141
23.	.308	.222	.875	.292	.361	.173	.146	.163	.143	.149	.147	.141
24	.302	.225	.835	.277	.355	.175	.146	.160	.147	.141	.153	.140
25	.278	.225	.750	.283	.325	.173	.134	.161	.139	.140	.147	.136
26	.280	.222	.692	.295	.293	.173	.140	.149	.147	.141	.140	.134
27	.284	.213	.620	.302	.389	.163	.137	.149	.147	.140	.141	.137
28	.291	.221	.589	.295	.302	.281	.163	.157	.149	.147	.140	.140
29	.302		.545	.289	.248	.163	.141	.147	.137	.134	.140	.141
30	.293		.513	.271	.238	.165	.140	.149	.147	.140	.170	.141
31	.293		.466		.236		.137	.153		.147		.141

For 1911

1	.130	.120	.256	.188	.167	.175	.124	.104	.149	.141	.465	.265
2	.133	.135	.256	.185	.169	.197	.115	.105	.149	.131	.428	.251
3	.134	.125	.248	.185	.167	.186	.109	.115	.139	.158	.395	.229
4	.135	.128	.234	.179	.167	.265	.113	.111	.149	.158	.378	.207
5	.138	.133	.222	.178	.156	.239	.111	.106	.158	.210	.378	.229
6	.139	.113	.244	.179	.149	.231	.113	.125	.147	2.01	.362	.288

DAILY RUNOFF AT ZUMBRO FALLS IN SECOND FEET PER SQUARE MILE

For 1911

Dy	J	F	Mr	Ap	My	Ju	Jy	Au	S	O	N	D
7	.156	.129	.224	.172	.149	.187	.108	.152	.141	2.85	.294	.288
8	.149	.124	.224	.179	.147	.185	.108	.226	.141	1.75	.464	.228
9	.145	.124	.234	.172	.148	.169	.108	.171	.137	1.14	.464	.227
10	.143	.127	.254	.172	.143	.167	.106	.177	.132	.838	.428	.957
11	.139	.124	.262	.175	.145	.167	.106	.167	.124	.658	.412	3.43
12	.139	.127	.256	.199	.143	.165	.106	.160	.133	.557	.362	1.78
13	.137	.145	.254	.206	.133	.149	.108	.196	.133	.482	.311	1.10
14	.137	1.20	.248	.206	.139	.147	.103	1.54	.131	.500	.332	.838
15	.137	2.11	.248	.211	.184	.147	.103	1.43	.127	.500	.311	.705
16	.131	1.31	.248	.184	.147	.166	.103	.848	.124	3.07	.277	.558
17	.133	1.55	.222	.199	.147	.172	.141	.586	.124	7.88*	.268	.464
18	.137	1.55	.222	.199	.147	.172	.141	.586	.124	7.44	.268	.464
19	.133	.707	.199	.199	.242	.172	.111	.361	.136	3.14	.232	.362
20	.136	.447	.203	.192	.273	.158	.106	.302	.147	2.01	.223	.362
21	.143	.428	.211	.187	.302	.149	.103	.268	.139	1.44	.214	.362
22	.131	.337	.203	.187	.637	.143	.103	.236	.135	1.03	.232	.332
23	.131	.311	.199	.177	.606	.143	.103	.231	.137	.883	.205	.318
24	.131	.318	.199	.153	.443	.143	.103	.233	.137	.793	.205	.290
25	.131	.324	.199	.167	.355	.139	.103	.188	.122	.722	.264	.284
26	.131	.327	.197	.165	.293	.139	.103	.186	.131	.929	.264	.247

*Note, Although this is an exceptionally low year, it will be interesting to note the extremely high water in October

DAILY RUNOFF AT ZUMBRO FALLS IN CUBIC FEET PER SQUARE MILE

For 1911

Dy	J	F	M	A	My	Ju	Jy	Au	S	O	N	D
27	.137	.295	.197	.153	.260	.139	.103	.186	.130	.836	.277	.180
28	.133	.265	.197	.158	.226	.139	.113	.160	.133	.734	.207	.189
29	.137		.192	.164	.197	.136	.103	.156	.131	.638	.179	.214
30	.144		.203	.164	.193	.136	.103	.153	.139	.577	.217	.205
31	.131		.186		.187		.102	.158		.450		.205

For 1912

Dy	J	F	M	A	My	Ju	Jy	Au	S	O	N	D
1		.207	.207	2.04	.457	.279	.252	.178	.207	.166	.169	
2		.207	.207	1.65	.430	.395	.277	.188	.207	.166	.168	
3		.207	.207	1.23	.430	.295	.240	.169	.207	.164	.169	
4		.207	.207	1.04	.430	.347	.332	.188	.188	.153	.168	
5		.207	.218	1.04	.505	.332	.412	.188	.188	.160	.168	
6		.207	.207	.128	.583	.303	.379	.197	.188	.157	.161	
7		.207	.207	1.95	.430	.277	.302	.169	.169	.152	.168	
8		.207	.207	1.57	4.12	.252	.252	.349	.168	.161	.164	
9		.207	.207	1.14	.362	.252	.252	.302	.168	.152	.168	
10		.207	.207	.938	.362	.252	.218	.338	.178	.160	.166	
11		.207	.207	.844	.333	.253	.290	.207	.166	.164	.166	
12		.207	.207	.750	.318	.229	.302	.207	.188	.177	.169	
13		.207	.197	.704	.202	.252	.364	.188	.169	.207	.197	
14		.228	.796	.289	.289	.247	.197	.178	.207	.207	.240	
15		.207	.207	1.52	.303	.318	.302	.197	.169	.207	.262	
16		.218	.208	1.27	.303	.290	.178	.169	.197	.197	.218	
17		.218	.252	.938	.303	.289	.277	.197	.169	.188	.207	

DAILY RUNOFF AT ZUMBRO FALLS IN CUBIC FEET PER SQUARE MILE

For 1912

	J	F	M	A	My	Ju	Jy	Au	S	O	N	D
18		.228	.796	.750	.289	.252	.228	.302	.178	.188	.207	
19		.228	2.32	.662	.621	.229	.228	.302	.178	.178	.188	
20		.228	1.89	.583	5.24	.231	.278	.256	.188	.178	.188	
21		.228	1.12	.632	2.84	.218	.277	.256	.188	.178	.188	
22		.228	.796	1.89	1.43	.207	.277	.252	.178	.178	.188	
23		.228	.706	1.84	1.23	.207	.302	.228	.169	.178	.188	
24		.241	.741	1.14	1.18	.218	.265	.207	.169	.169	.178	
25		.241	.843	.938	.844	.207	.332	.197	.169	.169	.169	
26		.218	.749	.750	.662	.207	.228	.188	.166	.169	.169	
27		.207	1.32	.662	.662	.207	.228	.188	.161	.178	.169	
28		.228	3.38	.601	.562	.197	.207	.188	.161	.169	.169	
29		.228	4.64	.543	.467	.187	.197	.188	.151	.169	.178	
30			2.57	.503	.430	.187	.178	.207	.160	.169	.166	
31			2.03		.395		.188	.207		.169		

*Note,-There are no records for January and December of the year 1912.

DAILY AND ACCUMULATIVE RUNOFF FOR THE YEAR 1910, AT ZUMBRO FALLS

DAY	J.	T.	F.	T.	Mr.	T.	Ap.	T.
1	.0144	0.0144	.0109	0.3668	.0089	0.6221	.0168	1.8905
2	.0142	0.1286	.0113	0.3781	.0088	0.6300	.0160	1.9065
3	.0141	0.0427	.0112	0.3894	.0097	0.6397	.0160	1.9125
4	.0139	0.0566	.0150	0.3998	.0107	0.6504	.0155	1.9280
5	.0138	0.0704	.0098	0.4097	.0136	0.6640	.0140	1.9420
6	.0136	0.0740	.0102	0.4199	.0376	0.7016	.0134	1.9556
7	.0134	0.0874	.0103	0.4302	.0930	0.7946	.0134	1.9690
8	.0139	0.0913	.0109	0.442	.0785	0.8731	.0132	1.9822
9	.0137	0.1050	.0105	0.5407	.0710	0.9441	.0123	1.9945
10	.0134	0.1184	.0100	0.4600	.0610	1.0051	.0121	2.0066
11	.0137	0.1321	.0097	0.4697	.0605	1.0656	.0121	2.0187
12	.0124	0.1445	.0099	0.4795	.0598	1.1254	.0119	2.0396
13	.0115	0.1550	.0095	0.4891	.0760	1.2124	.0117	2.0413
14	.0114	0.1664	.0097	0.4988	.0810	1.2930	.0111	2.0524
15	.0113	0.1777	.0098	0.5096	.0650	1.3580	.0115	2.0639
16	.0114	0.1891	.0095	0.5191	.0535	1.4115	.0111	2.0750
17	.0114	0.2005	.0092	0.5283	.0470	1.4580	.0114	2.0864
18	.0113	0.2118	.0093	0.5376	.0432	1.5003	.0111	2.0975
19	.0113	0.2231	.0092	0.5468	.0398	1.5401	.0112	2.1087
20	.0119	0.2350	.0089	0.5557	.0398	1.5799	.0112	2.1197
21	.0119	0.2469	.0088	0.5645	.0398	1.6197	.0110	2.1307
22	.0114	0.2583	.0088	0.5733	.0364	1.5561	.0110	2.1417
23	.0114	0.2697	.0082	0.5815	.0323	1.6884	.0108	2.1525

DAILY AND ACCUMULATIVE RUNOFF FOR THE YEAR 1910, AT ZUMBRO FALLS

DAY	J.	T.	F.	T.	Mr.	T.	Ap.	T.
24	.0112	0.2809	.0084	0.5899	.0310	1.7194	.0103	2.1628
25	.0103	0.2912	.0884	0.5983	.0278	1.7472	.0105	2.1733
26	.0104	0.3016	.0082	0.6065	.0257	1.7729	.0109	2.1842
27	.0105	0.3121	.0079	0.6144	.0221	1.7950	.0112	2.1954
28	.0108	0.3229	.0079	0.6223	.0219	1.8169	.0109	2.2063
29	.0112	0.3341			.0202	1.8371	.0107	2.2170
30	.0109	0.3450			.0190	1.8560	.0101	2.2201
31	.0109	0.3559			.0177	1.8737		

	My.	T.	Ju.	T.	Jy.	T.	Au.	T.
1.	.0099	2.2300	.0086	2.5475	.0060	2.7590	.0050	2.9277
2	.0097	2.2397	.0084	2.5559	.0060	2.7650	.0055	2.9332
3	.0099	2.2496	.0080	2.5639	.0060	2.7710	.0055	2.9387
4	.0092	2.2588	.0082	2.5721	.0059	2.7779	.0050	2.9437
5	.0092	2.2680	.0079	2.5800	.0056	2.7835	.0050	2.9487
6	.0094	2.2774	.0080	2.5880	.0060	2.7895	.0050	2.9537
7	.0092	2.2866	.0077	2.5957	.0059	2.7954	.0050	2.9587
8	.0089	2.2955	.0077	2.6034	.0059	2.8053	.0050	2.9537
9	.0088	2.3043	.0076	2.6110	.0060	2.8113	.0050	2.9787
10	.0088	2.3131	.0076	2.6186	.0065	2.8169	.0050	2.9837
11	.0086	2.3217	.0076	2.6262	.0054	2.8213	.0051	2.9888
12	.0088	2.3305	.0075	2.6337	.0059	2.8272	.0053	2.9941
13	.0088	2.3393	.0073	2.6410	.0057	2.8329	.0055	2.9996
14	.0088	2.3481	.0072	2.6482	.0056	2.8385	.0055	3.0551

DAILY AND ACCUMULATIVE RUNOFF FOR THE YEAR 1910,AT

ZUMBRO FALLS

Day	My.	T.	Ju.	T.	Jy.	T.	Au.	T.
15	.0087	2.3568	.0071	2.6553	.0055	2.8440	.0056	3.0607
16	.0084	2.3662	.0070	2.6623	.0055	2.8495	.0061	3.0668
17	.0108	2.3860	.0071	2.6694	.0057	2.8552	.0079	3.0747
18	.0105	2.3965	.0071	2.6765	.0053	2.8605	.0076	3.0823
19	.0106	2.4071	.0069	2.6830	.0054	2.8559	.0076	3.0899
20	.0105	2.4176	.0065	2.6895	.0056	2.8715	.0069	3.0968
21	.0102	2.4278	.0067	2.6962	.0053	2.8768	.0062	3.1030
22	.0127	2.4405	.0067	2.7029	.0053	2.8831	.0060	3.1090
23	.0134	2.4539	.0054	2.7093	.0053	2.8874	.0060	3.1150
24	.0132	2.4761	.0065	2.7158	.0051	2.8925	.0059	3.1209
25	.0121	2.4729	.0064	2.7222	.0049	2.8974	.0060	3.1269
26	.0109	2.4901	.0064	2.7286	.0051	2.9025	.0055	3.1324
27	.0104	2.5005	.0061	2.7347	.0050	2.9074	.0055	3.1379
28	.0098	2.5113	.0061	2.7408	.0051	2.9126	.0055	3.1434
29	.0092	2.5212	.0061	2.7469	.0051	2.9177	.0055	3.1489
30	.0089	2.5310	.0061	2.7530	.0050	2.9337	.0055	3.1544
31	.0088	2.5389			.0050	2.9277	.0057	3.160

DAILY AND ACCUMULATIVE RUNOFF FOR THE YEAR 1910, AT ZUMBRO FALLS

DAY	S	T	O	T	N	T	D	T
1	.0060	3.1661	.0053	3.3276	.0051	3.3889	.0052	3.6527
2	.0051	3.1712	.0053	3.3329	.0056	3.4945	.0055	3.5682
3	.0055	3.1767	.0053	3.3382	.0056	3.5001	.0057	3.6639
4	.0054	3.1821	.0053	3.3535	.0056	3.5057	.0052	3.6691
5	.0056	3.1877	.0053	3.3498	.0056	3.5113	.0055	3.6746
6	.0058	3.1935	.0053	3.3551	.0056	3.5169	.0052	3.6798
7	.0056	3.1993	.0053	3.3604	.0056	3.5225	.0055	3.9653
8	.0056	3.2049	.0051	3.3655	.0056	3.5281	.0045	3.6898
9	.0054	3.2103	.0050	3.3705	.0055	3.5336	.0052	3.6950
10	.0054	3.2157	.0050	3.3755	.0055	3.5391	.0052	3.7002
11	.0056	3.2213	.0051	3.3806	.0055	3.5446	.0049	3.7051
12	.0051	3.2264	.0051	3.3857	.0056	3.5502	.0049	3.7100
13	.0055	3.2319	.0051	3.3908	.0053	3.5555	.0050	3.7150
14	.0055	3.2346	.0050	3.3958	.0051	3.5606	.0051	3.7201
15	.0055	3.2419	.0050	3.4008	.0056	3.5662	.0051	3.7252
16	.0055	3.2474	.0050	3.4058	.0050	3.712	.0052	3.7304
17	.0054	3.2528	.0049	3.4107	.0051	3.5763	.0053	3.7357
18	.0052	3.2580	.0049	3.4156	.0051	3.5820	.0052	3.7409
19	.0049	3.2629	.0053	3.4209	.0056	3.5877	.0052	3.7461
20	.0051	3.2680	.0055	3.4259	.0056	3.5933	.0051	3.7512
21	.0050	3.2730	.0056	3.4315	.1156	3.5988	.0052	3.7564
22	.0053	3.2783	.0056	3.4371	.0052	3.6040	.0052	3.7616
23	.0053	3.2836	.0056	3.4427	.0055	3.6095	.0052	3.7668

DAILY AND ACCUMULATIVE RUNOFF FOR THE YEAR 1910, AT ZUMBRO FALLS

DAY	S.	T.	O.	T.	N.	T.	D.	T.
24	.0055	3.4891	.0052	3.4479	.0057	3.6152	.0052	3.7720
25	.0052	3.2943	.0052	3.4531	.0055	3.6207	.0050	3.7770
26	.0055	3.2998	.0052	3.4573	.0052	3.6259	.0049	3.7819
27	.0055	3.3053	.0052	3.4625	.0052	3.6311	.0051	3.7870
28	.0055	3.3108	.0055	3.4680	.0051	3.6362	.0051	3.7921
29	.0060	3.3168	.0051	3.4731	.0050	3.6412	.0052	3.7973
30	.0055	3.3223	.0052	3.4783	.0063	3.6475	.0052	3.8025
31			.0055	3.4838			.0052	3.8077

DAILY PRECIPITATION FOR THE YEAR 1910

JANUARY

DAY	F	RL	R	WC	W	Z	AVE.	SUM
1								0.00
2	8.03				t	t	0.005	0.005
3	0.01	0.04			t		0.01	0.015
4	0.11			0.40	0.30	0.57	0.21	0.225
5	0.14	0.35	0.60		0.22		0.22	0.445
6								0.445
7	t				t	t	t	0.445
8		0.02			t		0.003	0.448
9								0.448
10								0.448
11								0.448
12								0.448
13	0.17	0.12	0.70	0.60	0.40	0.30	0.38	0.828
14		0.03	0.20				0.04	0.868
15					t			0.868
16	t				t		t	0.868
17	0.02			0.10	t	t	0.02	0.886
18	t	0.05	0.15		0.10		0.05	0.938
19								0.938
20	t			0.10	t	t	0.016	0.954
21								0.954
22								0.954
23								0.954

DAILY PRECIPITATION FOR THE YEAR 1910

JANUARY

Day	F	RL	R	WC	W	Z	AVE.	SUM
24								0.954
25								0.954
26	0.02			0.10	0.05		0.03	0.984
27			0.25	t	t		0.04	1.024
28					t			1.024
29	t				t	t	t	1.024
30		t	t		t		t	1.024
31								1.024

FEBRUARY

Day	F	RL	R	WC	W	Z	AVE.	SUM
1								1.024
2	t				t	t	t	1.024
3								1.024
4								1.024
5								1.024
6								1.024
7								1.024
8								1.024
9	t							1.024
10								1.024
11	t		t		t		t	1.024
12								1.024
13								1.024
14		t						1.024

DAILY PRECIPITATION FOR THE YEAR 1910

FEBRUARY

DAY	F	RL	R	WC	W	Z	AVE.	SUM.
15	0.02			t	0.02		0.007	1.031
16		0.01			t	t	0.001	1.032
17								1.032
18								1.032
19								1.032
20	0.01		t		0.06		0.011	1.043
21		0.04	0.05				0.015	1.058
22	0.02		t	t	0.02		0.006	1.064
23		0.04					0.006	1.070
24	0.01		t		t	t	0.001	1.071
25								1.071
26			t		0.04		0.006	1.077
27								1.077
28								1.077

MARCH

DAY	F	RL	R	WC	W	Z	AVE.	SUM.
1	0.02	t	t		0.02	0.02	0.01	1.087
2								1.087
3						t		1.087
4					t		t	1.087
5								1.087
6								1.087
7					t		t	1.087
8								1.087

DAILY PRECIPITATION FOR THE YEAR 1910

MARCH

DAY	F	RL	R	WC	W	Z	AVE.	SUM
9								1.087
10								1.087
11								1.087
12								1.087
13								1.087
14								1.087
15								1.087
16								1.087
17								1.087
18								1.087
19								1.087
20								1.087
21								1.087
22								1.087
23								1.087
24								1.087
25								1.087
26								1.087
27								1.087
28								1.087
29	0.21						0.033	1.120
30	0.02	t	t				0.006	1.126
31				t			t	1.126

DAILY PRECIPITATION FOR THE YEAR 1910

APRIL

DAY	F	RL	R.	WC	W	Z	AVE	SUM
1								1.126
2								1.126
3								1.126
4					0.21		0.036	1.162
5					0.20		0.033	1.195
6								1.195
7					t	t	t	1.195
8								1.195
9								1.195
10								1.195
11						t	t	1.195
12		0.16					0.026	1.221
13								1.221
14	0.03						0.005	1.226
15	0.01	0.02	0.13	0.20	0.11		0.076	1.302
16	t	t		0.20	0.28	0.30	0.130	1.432
17	0.10	0.10	0.24	0.30	0.16	t	0.15	1.582
18	0.01	0.04	0.25	0.20	0.01	t	0.093	1.675
19		0.24	t				0.04	1.679
20								1.679
21								1.679
22	0.10	0.04	t	0.30	0.03		0.16	1.839
23	0.10			0.50	0.12	0.10	0.136	1.975

DAILY PRECIPITATION FOR THE YEAR 1910

APRIL

DAY	F	RL	R	WC	W	Z	AVE.	SUM
24	0.14	0.12	0.05		0.08		0.065	2.040
25					t			2.040
26								2.040
27								2.040
28								2.040
29								2.040
30								2.040

MAY

DAY	F	RL	R	WC	W	Z	AVE.	SUM
1								2.040
2								2.040
3								2.040
4								2.040
5								2.040
6								2.040
7								2.040
8								2.040
9								2.040
10								2.040
11								2.040
12								2.040
13								2.040
14								2.040
15	t		t		0.75	0.55	0.217	2.257

DAILY PRECIPITATION FOR THE YEAR 1910

MAY

DAY	F	RL	R	WC	W	Z	AVE.	SUM
16	0.31	0.01		0.22			0.09	2.347
17	0.61	1.42	1.42	0.82	0.79	0.78	0.97	3.317
18		0.08	0.10				0.03	3.347
19								3.347
20	0.13	0.08	0.08			0.92	0.203	3.550
21	0.47		0.05	0.92	1.33		0.462	4.012
22	0.01	1.20	0.70	0.02	0.05		0.660	4.672
23					0.03		0.005	4.677
24		0.06			0.02		0.013	4.790
25		0.04					0.006	4.796
26								4.796
27								4.796
28	0.02	0.02	t	t	0.01	t	0.008	4.804
29	0.01	0.02					0.005	4.809
30								4.809
31	0.06							4.819

JUNE

DAY	F	RL	R	WC	W	Z	AVE.	SUM
1								4.819
2								4.819
3	0.04			t			0.006	4.825
4								4.825
5	0.12			0.04	0.02		0.03	4.855
6		0.14			0.22		0.09	4.945

DAILY PRECIPITATION FOR THE YEAR 1910

JUNE

DAY	F	RL	R	WC	W	Z	AVE.	SUM
7								4.945
8	t						t	4.945
9	t				0.01		0.002	4.947
10								4.947
11								4.947
12								4.947
13								4.947
14								4.947
15								4.947
16								4.947
17					t		t	4.947
18					t		t	4.947
19								4.947
20								4.947
21								4.947
22								4.947
23								4.947
24								4.947
25								4.947
26	0.23				t		0.06	4.953
27								4.953
28								4.953
29								4.953
30								4.953

DAILY PRECIPITATION FOR THE YEAR 1910

JULY

DAY	F	RL	R	WC	W	Z	AVE.	SUM
1								4.953
2								4.953
3								4.953
4								4.953
5								4.953
6	0.75	0.28	0.26	0.20		0.08	0.262	5.215
7								5.215
8								5.215
9	0.94	0.42	0.27	0.67	0.13	0.76	0.534	5.749
10		0.14	0.16				0.05	5.799
11	0.27			0.05			0.053	5.852
12	0.17	0.08			0.02		0.055	5.907
13								5.907
14								5.907
15								5.907
16								5.907
17		0.74	0.15		0.02		0.152	6.059
18								6.059
19								6.059
20								6.059
21								6.059
22								6.059
23	0.04	0.14		t	0.26		0.073	6.132

DAILY PRECIPITATION FOR THE YEAR 1910

JULY

DAY	F	RL	R	WC	W	Z	AVE.	SUM
24		0.04			0.15		0.033	6.165
25								6.165
26								6.165
27	0.10			t	t	t	0.016	6.181
28								6.181
29								6.181
30								6.181
31	t						t	6.181
				AUGUST				
1	0.20		0.15	0.50			0.142	6.323
2	0.29	0.16			0.05	0.10	0.10	6.423
3		0.04		0.10	0.29		0.062	6.485
4								6.485
5								6.485
6								6.485
7				1.00		0.10	0.184	6.669
8	0.35	0.50	0.12	0.03	0.11	0.20	0.218	6.897
9		0.68			0.11		0.13	7.027
10								7.027
11				0.25	0.32	t	0.095	7.122
12		0.38	0.68		0.25	0.32	0.268	7.390
13	0.15		0.09	0.18		0.08	0.084	7.474
14			0.05		0.01	0.81	0.145	7.619

DAILY PRECIPITATION FOR THE YEAR 1910

AUGUST

DAY	F	RL	R	WC	W	Z	AVE.	SUM
15	0.37			0.40	0.32		0.182	7.852
16	0.07	0.22	0.46				0.125	7.967
17		0.52	0.50	0.75	1.02	1.02	0.635	8.511
18		0.50	0.05		0.13		1.113	8.724
19								8.724
20								8.724
21								8.724
22								8.724
23								8.724
24								8.724
25		0.18	0.09		0.04	0.03	0.056	8.780
26								8.780
27								8.780
28	t			t	0.14		0.026	8.806
29				0.02	0.45	0.10	0.083	8.889
30	0.54	0.56	0.75	0.40		0.30	0.425	9.314
31								9.314
				SEPTEMBER				
1								9.314
2	0.01						0.003	9.317
3						0.01	0.003	9.320
4	0.15			t	t		0.025	9.345
5	0.10	0.56	0.85	0.50	2.11		0.685	10.030

DAILY PRECIPITATION FOR THE YEAR 1910

SEPTEMBER

DAY	F	RL	R	WC	W	Z	AVE.	SUM
6		0.04			t		0.006	10.036
7								10.036
8								10.036
9								10.036
10								10.036
11	0.16			0.60	0.03		0.132	10.168
12		0.58	0.05		0.22		0.125	10.293
13	0.01		t		0.01		0.003	10.296
14								10.296
15								10.296
16								10.296
17								10.296
18								10.296
19								10.296
20								10.296
21								10.296
22	t				0.01		0.002	10.298
23								10.298
24		0.44	0.46		0.95		0.324	10.622
25	0.14			0.20			0.056	10.678
26	1.02	0.28	0.40	1.60	0.69		0.666	11.344
27		0.18	0.22				0.066	11.410
28								11.410

DAILY PRECIPITATION FOR THE YEAR 1910

SEPTEMBER

DAY	F	RL	R	WC	W	Z	AVE.	SUM
29								11.410
30								11.410

OCTOBER

DAY	F	RL	R	WC	W	Z	AVE.	SUM
1								11.410
2								11.410
3	0.17			t	0.06		0.040	11.450
4				t				11.450
5								11.450
6								11.450
7								11.450
8								11.450
9								11.450
10								11.450
11								11.450
12		0.80					0.133	11.583
13								11.583
14								11.583
15								11.583
16								11.583
17								11.583
18	0.19						0.032	11.615
19	0.03	0.26	0.10	0.09	0.26		0.123	11.738
20	0.06			t	t		0.010	11.748

DAILY PRECIPITATION FOR THE YEAR 1910

OCTOBER

DAY	F	RL	R	WC	W	Z	AVE	SUM
21	0.20	0.08	0.16	0.02	0.67		0.172	11.956
22		0.24			t		0.040	11.996
23								11.996
24	0.02			t			0.003	11.999
25	0.01			t			0.002	12.001
26					0.01		0.002	12.003
27	t			t	0.04		0.006	12.009
28	t	0.01	t	t	t		0.002	12.011
29								12.011
30								12.011
31								12.011

NOVEMBER

DAY	F	RL	R	WC	W	Z	AVE	SUM
1	0.14	0.03	t	0.20	0.33	0.13	0.132	12.143
2	t	0.28	0.20		0.03		0.083	12.226
3								12.226
4					0.01	0.02	0.005	12.231
5		0.08					0.013	12.244
6								12.244
7								12.244
8								12.244
9					t			12.244
10								12.244
11								12.244

DAILY PRECIPITATION FOR THE YEAR 1910

NOVEMBER

DAY	F	RL	R	WC	W	Z	AVE	SUM
12								12.244
13								12.244
14	0.19	0.04	t	0.10	0.05		0.066	12.310
15				t				12.310
16								12.310
17								12.310
18								12.310
19								12.310
20	0.01					t	0.002	12.312
21			0.02		0.02		0.006	12.318
22	0.04						0.006	12.324
23								12.324
24								12.324
25								12.324
26								12.324
27			t		t	t		12.324
28								12.324
29								12.324
30								12.324

DAILY PRECIPITATION FOR THE YEAR 1910

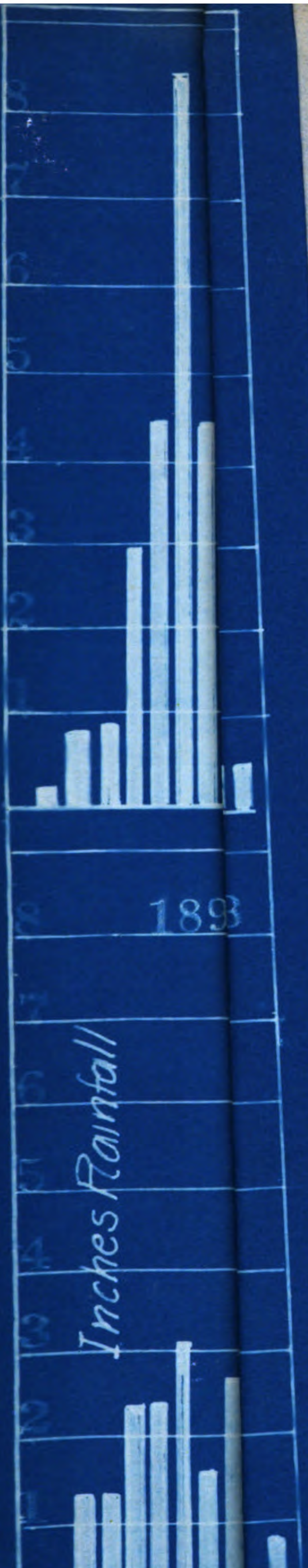
DECEMBER

DAY	F	RL	R	WC	W	Z	AVE	SUM
1								12.324
2								12.324
3								12.324
4					0.04		0.006	12.330
5								12.330
6		t	t	t	0.01		0.002	12.332
7	0.01	0.01	t		t	t	0.003	12.335
8								12.335
9								12.335
10					0.08		0.013	12.348
11								12.348
12								12.348
13								12.348
14								12.348
15								12.348
16								12.348
17								12.348
18					0.02		0.003	12.351
19	0.02						0.003	12.354
20								12.354
21								12.354
22		0.13		t	0.05	0.10	0.040	12.394
23	0.01	0.20	0.15		0.05		0.040	12.434

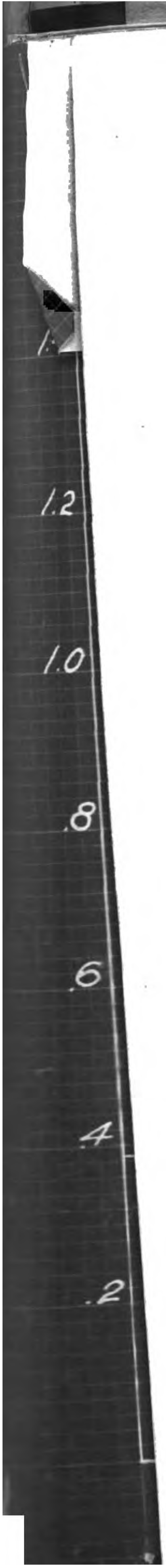
DAILY PRECIPITATION FOR THE YEAR 1910

DECEMBER

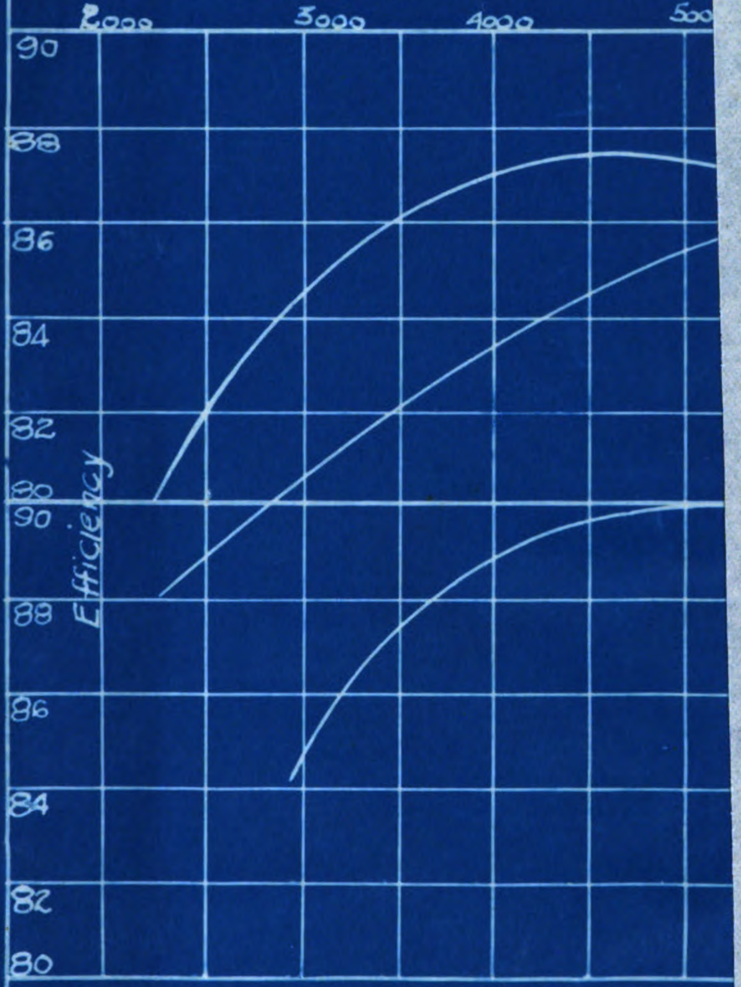
DAY	F	RL	R	WC	W	Z	AVE	SUM
24								12.434
25	0.13	0.08	0.30	0.30	0.18	0.07	0.193	12.627
26								12.627
27								12.627
28								12.627
29								12.627
30								12.627
31								12.627



8
7
6
5
4
3
2
1
189
8
7
6
5
4
3
2
1
Inches Rainfall


1.2
1.0
.8
.6
.4
.2

Ks Effiency Curve



A- Wellman Seaver Morg

B- James Leffel & Co

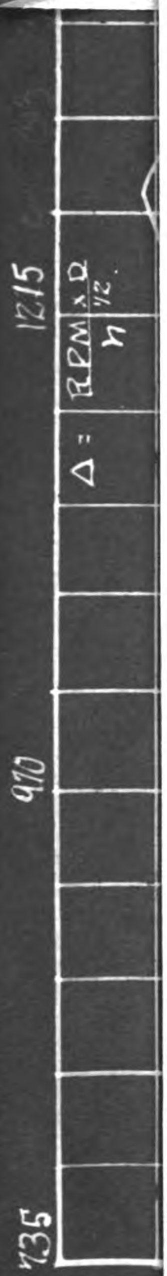
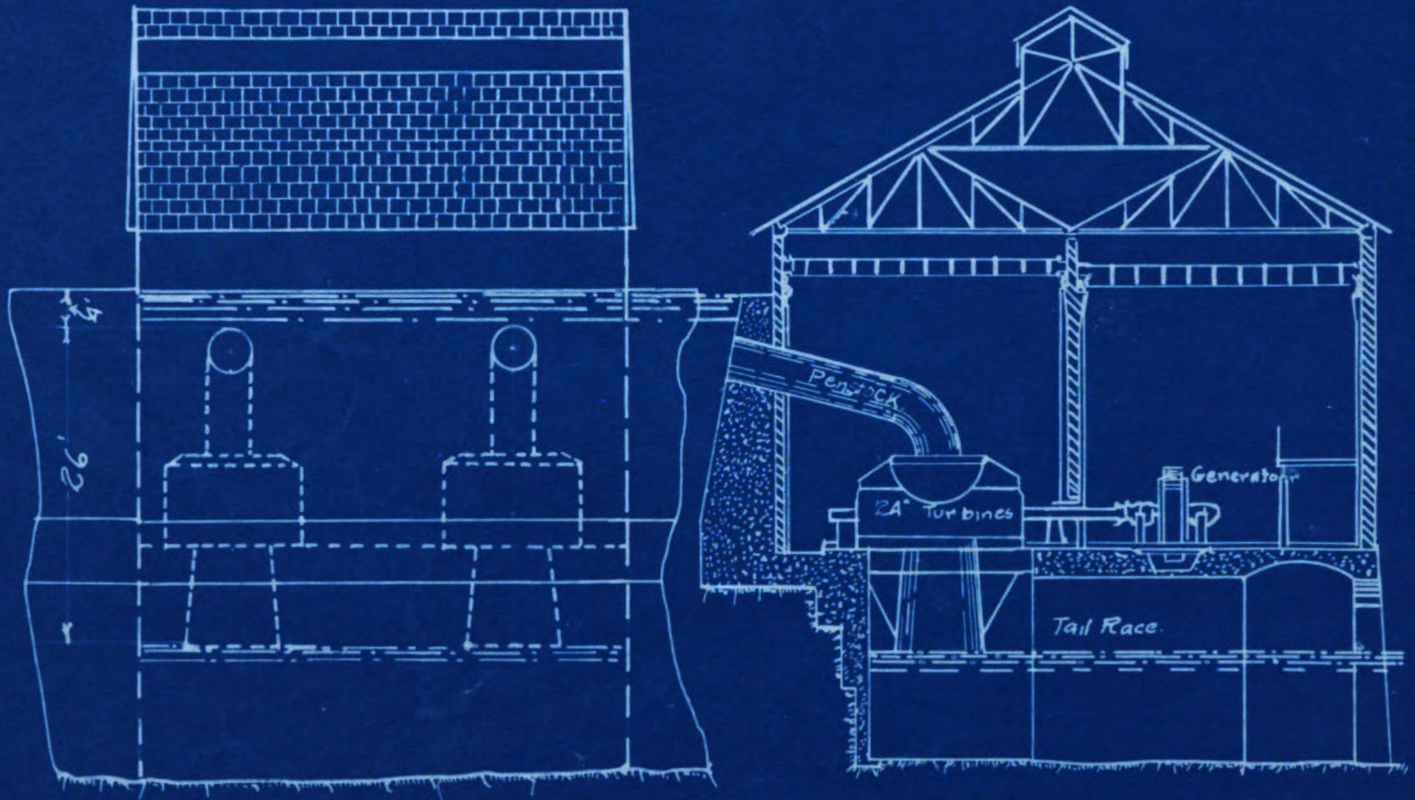

1215
Δ = RPM × D / n^½
910
735

Plate XVII

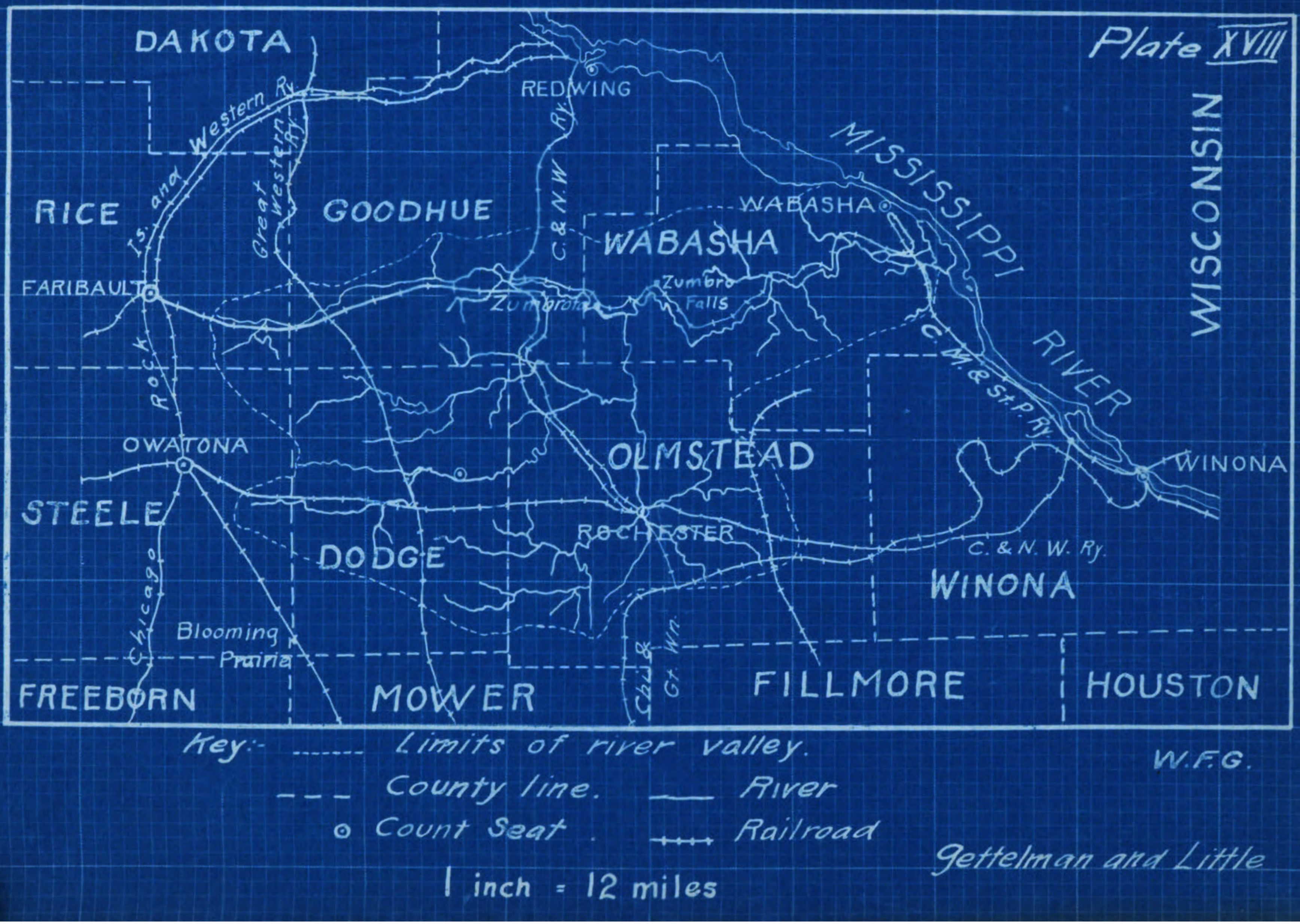


SKETCH OF PROPOSED POWER HOUSE AT
ZUMBRO FALLS - MINNESOTA. U.S.A.

SCALE 3/64" = 1'

C.B.L.

MAP OF ZUMBRO RIVER VALLEY



Approved by:-

H. L. Garner

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